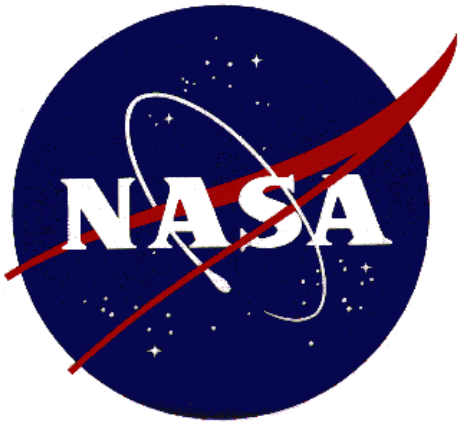

Economic Metrics for Commercial Space Transportation and Joint Industry/Government Technology Development

Presented to the Y2K NASA Cost Estimating Symposium

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Systems Management Office

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Topics

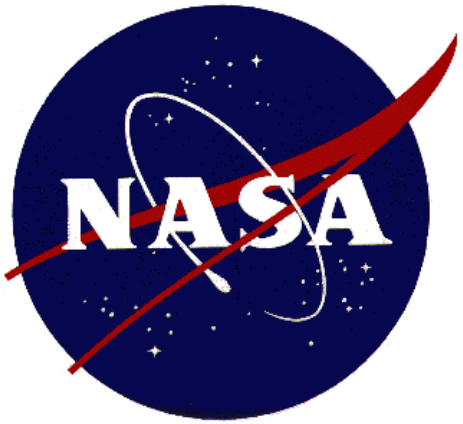
- Background
  - STAS99
  - ISTP
  - SLI
- Customer Viewpoints
- Economic Modeling
- Economic Metrics
- Other Related Topics

Disclaimer

This briefing does not reflect the final economic analysis of the Space Transportation Architecture Studies, nor the overall conclusions of the STAS, the Integrated Space Transportation Plan, nor the Space Launch Initiative.

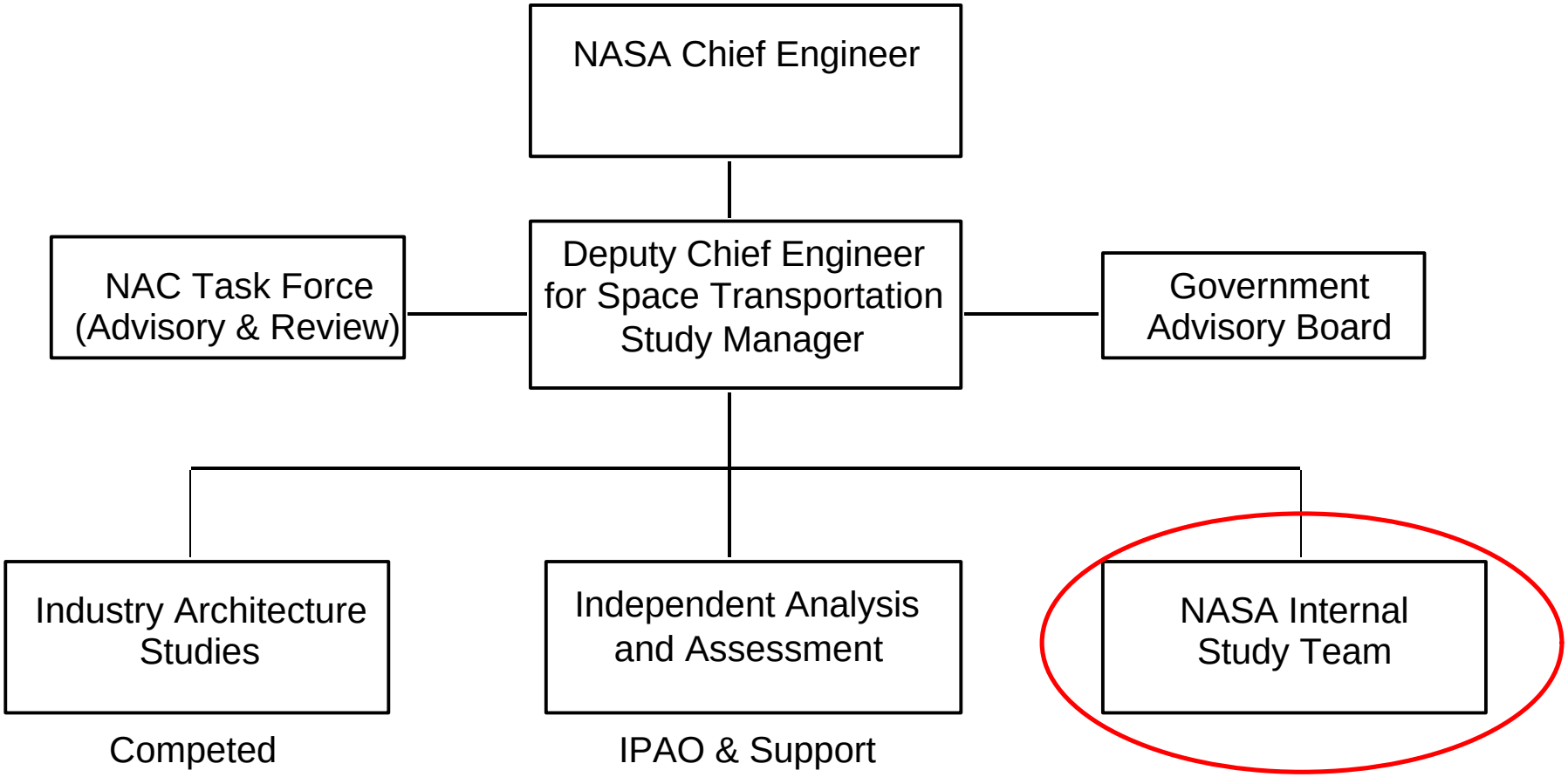
Additional STAS info: http://www.hq.nasa.gov/office/codea/codeae/sta_study.html

Additional SLI info: http://std.msfc.nasa.gov/spacelaunch.html



Background

The 1999 NASA Space Transportation Architecture Study (STAS99), Phase II Structure



STAS99, ISTP and SLI

- STAS99 Phase II Led by NASA Chief Engineer & Deputy
  - Five contracted teams
  - One NASA Internal Study Team, representing Centers and the Air Force
  - One independent team, led by NASA IPAO
- Five contracted team efforts end in May with STAS Phase IIIB
- NASA Internal Study Team Members continue to support ISTP
  - Integrated Space Transportation Plan of Codes M & R; also Codes S, U, Y
- ISTP Presented to Office of Management & Budget (OMB)
- Space Launch Initiative (SLI) in President's Budget announced by the NASA Administrator, yet to be approved by Congress
- New SLI efforts planned for March (Systems Requirements and Definition) and early Fall (RLV Technology), plus ISAT

STAS NASA Team Conclusions

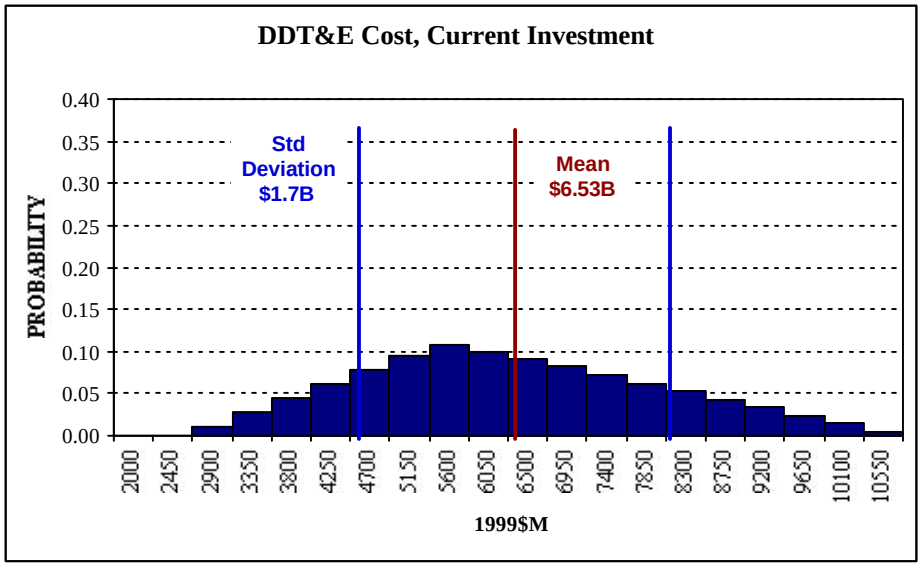
- Most Architectures' LCCs within ± 10% (2030 Discounted, to NASA; except EELV)
  - Time phasing of expenditures significantly different
- All Architectures with new elements bust the budget in peak years
  - Incentivized Commercial Approach reduces peak year funding but also outyear savings
- New Market Potential will not motivate commercial providers to $1000/lb price
  - Will not help justify developing new systems nor lowering commercial flight prices
  - Inexpensive "coach-class" flights are high-risk, lack short-term profitability
  - However, acquisition process could provide motivation & help attain low-price goal
    - E. g., incentive approval could favor commitment to low-price service for new customers

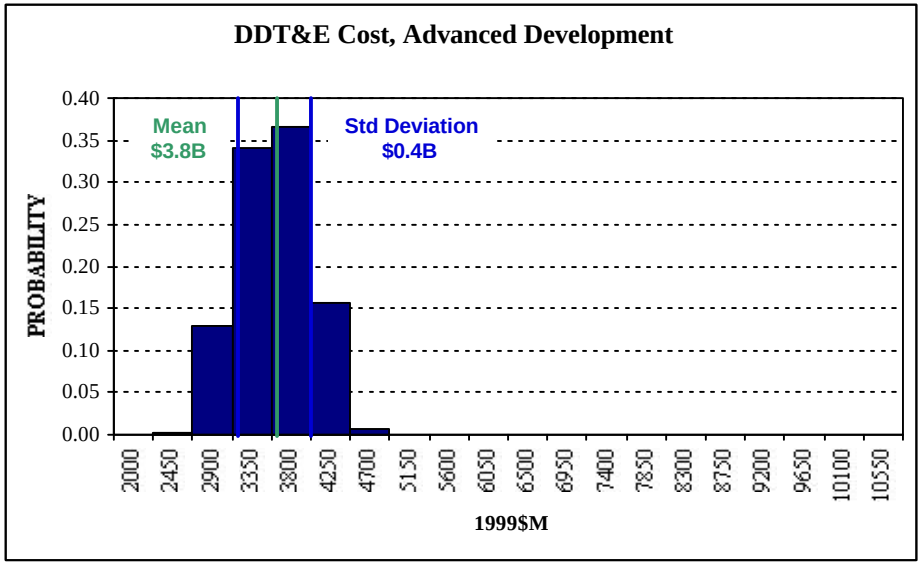
If NASA is primarily interested in maintaining the unique capabilities of the Space Shuttle, while reducing its costs for ISS transportation at low risk, it should pursue Architecture 1, knowing that eventually Shuttle will have to be replaced

If NASA is interested in stimulating the commercial market and enabling an expansion of the U.S. market share, it should pursue Architecture 4 or 5

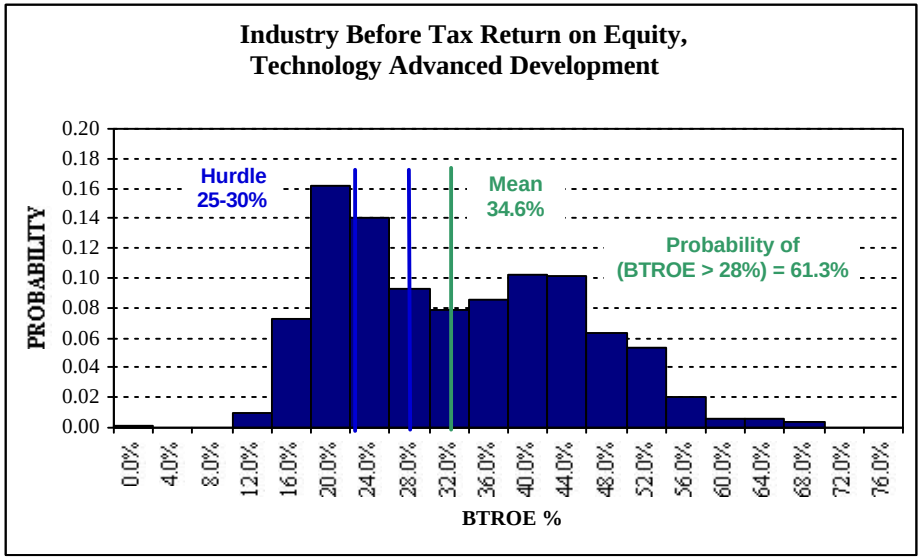
ISTP: Advanced Development (One System)

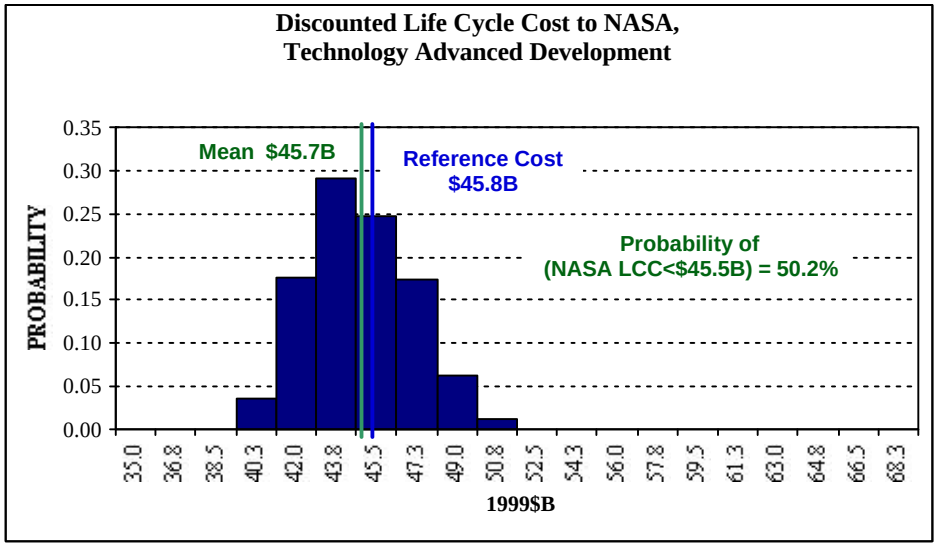
- Pre-ISTP Estimates: Initial DDT&E cost uncertainty range $3B to $13B
- Low Technology Investment Scenario
  - Subsystem risk addressed, but not system-level and integration risks, design immaturity
  - One immature subsystem could stop system progress or force system redesign
- ISTP High Technology Investment Scenario (Advanced Development)
  - Subsystem, system-level and integration risks retired
  - Experienced teams, mature industrial capability, higher design fidelity
- Subsequent estimated DDT&E Cost uncertainty range: $3B to $6B
- System Cost estimates constructed using NAFCOM99 Complexity Generators
- One System only! Competition further increases the probability of success

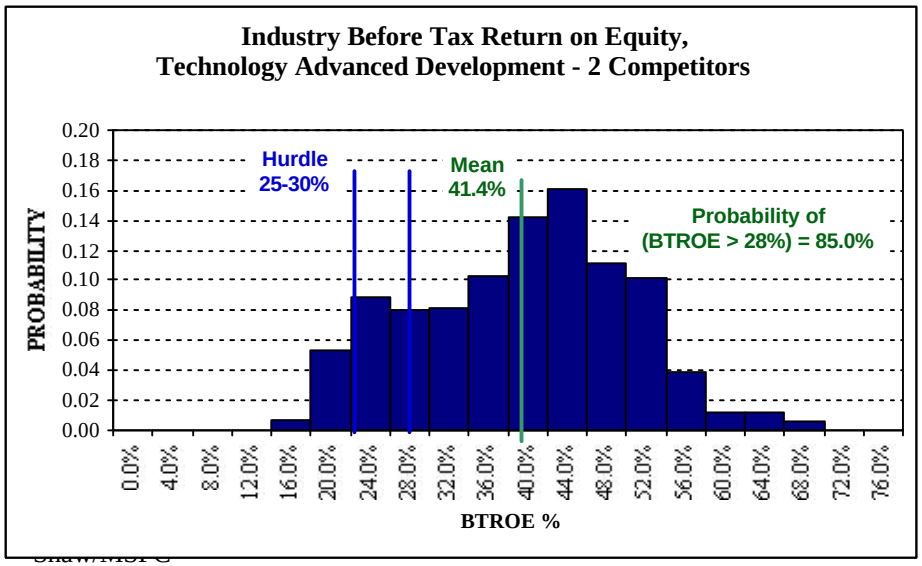


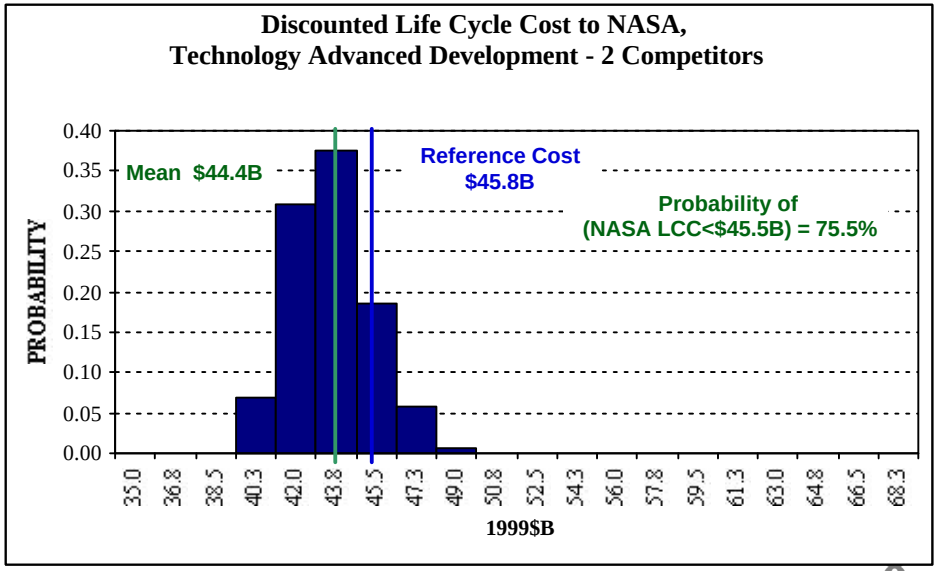


Increased Probability of Success From Competition





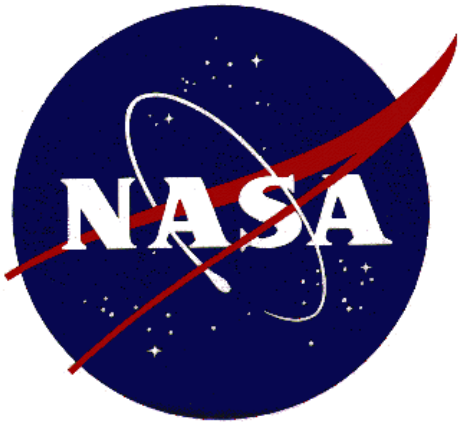




Focus Areas for ISTP Economic Analysis

All analyses based on Architecture-Level Economic Metrics

- Technology Prioritization — 1990 - Concepts Focus (~2003)
  - What technology investment areas have the most economic leverage?
- Incentive Evaluation — 1993 - Concepts Focus
  - What is the most economical path to the desired results?
- Sanity Checks — 1993 - ATP (~2005)
  - Do the Industry cost and price numbers make sense?
- Architecture Optimization — 1998* - Concepts Focus
  - How can the economic strengths of each architecture be maximized? (*New Design vehicle system business cases explored since early 1990's)
- Architecture Evaluation — 1998 - ATP
  - What are the "requirements?" How much will each "requirement" cost? Which architecture(s) satisfy the "requirements" most economically?
  - What other benefits can be expected?



Customer Viewpoints

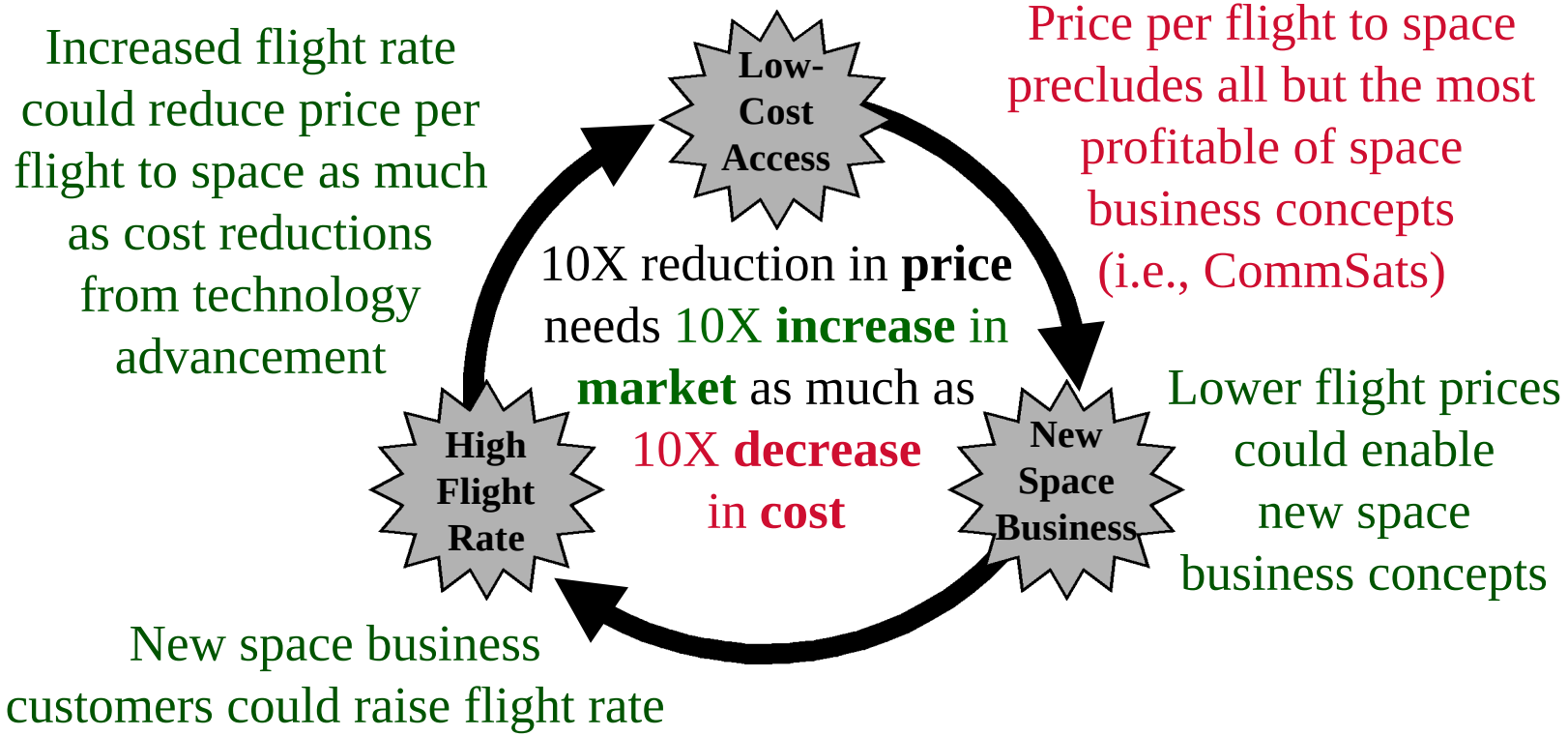
The Big Picture: Constraints to Business in Space

- Transportation into and within space
  - Cost*
  - Reliability
  - Availability
  - Flexibility
- Difficulties of the space environment
  - Physical (vacuum, orbital debris, radiation, etc.)
  - Financial (high risk or perception)
  - Regulatory (safety, re-entry)
  - Policy (lack of multi-year funding, juste retour)
  - Legal (liability)

* focus of economic analysis

The Chicken and the Egg

- Which comes first?
  - Revolutionary low-price reusable space transportation, or
  - New space industry customers that use low-price launchers
- How have we broken this vicious circle before?

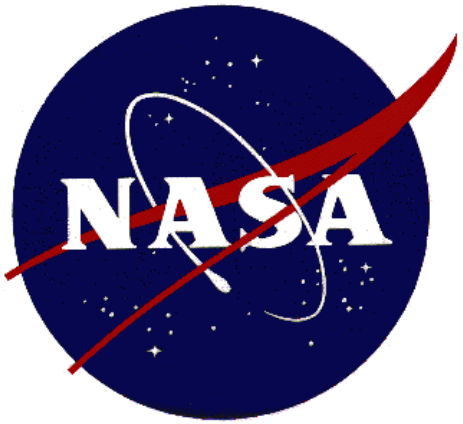


Government Investments in Transportation Technology and Infrastructure

- Governments can make large, long-term investments
  - Risk tolerance, low cost of money, macroeconomic outlook
- Railroads
  - Rapid expansion in the East, Westward routes not profitable
  - Transcontinental expansion motivated by land grants
  - Land grants made to facilitate Reconstruction after Civil War
  - Magnitude of ultimate benefits unforeseen
- Aviation Technology and Interstate Highways
  - Investments driven largely by military needs
  - Budget justification assisted by civilian economic value
  - Magnitude of ultimate benefits unforeseen

US Gov't Goals for Space Transportation

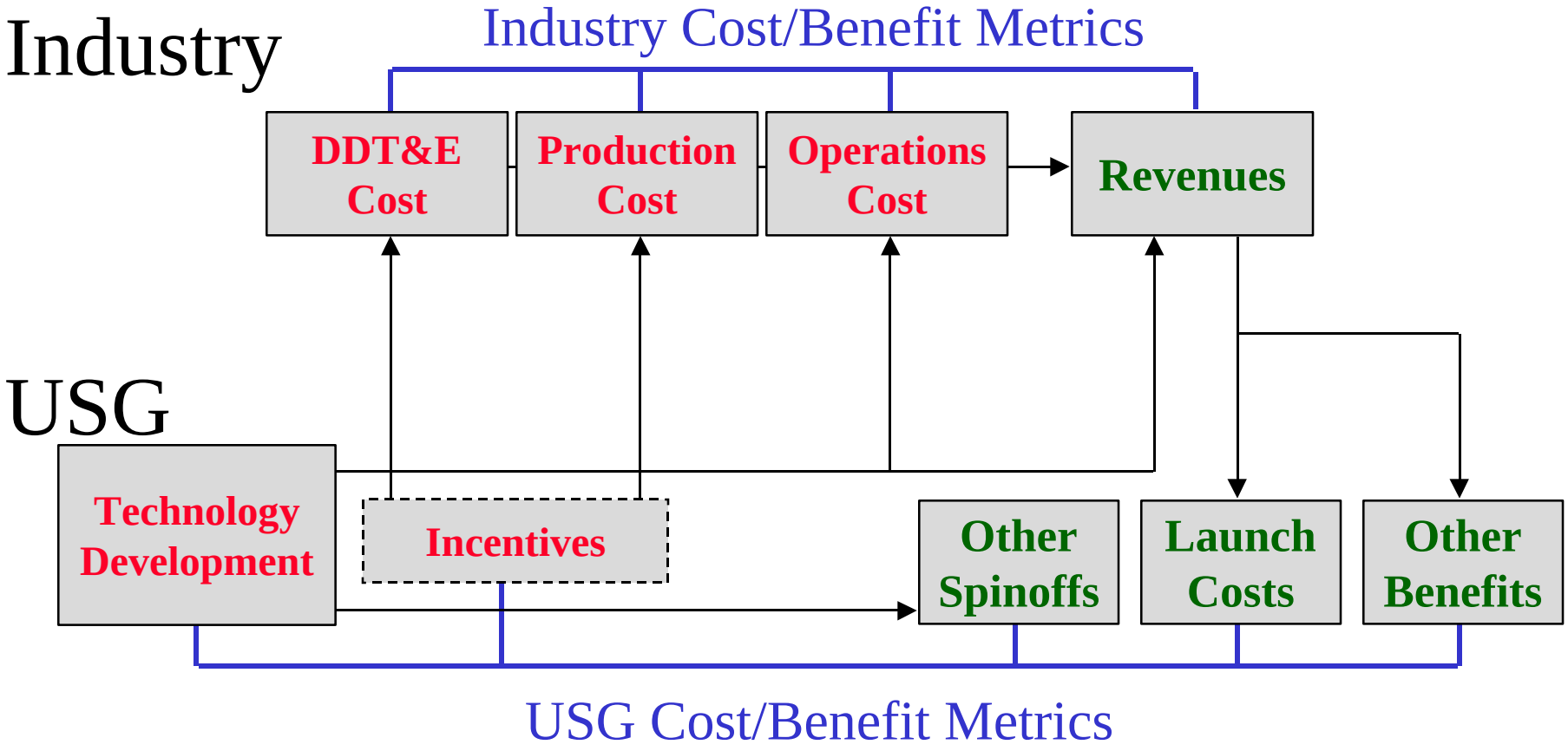
- Reducing the risk and cost of access to space is **third** on NASA's list of its most important priorities
  - Space Transportation is the Top Development Goal
  - Implementation Goals: Shuttle and Int'l Space Station
- NASA Code R Goals
  - Safety: order-of-magnitude improvement (LOC " 1/10,000)
    - Reliability: order-of-magnitude improvement (LOV " 1/1000)
  - Cost: order-of-magnitude improvement ("cost" " $1000/lb)
    - Code M Goal of enabling Human Exploration
- Administration (OMB) and Congressional Goals
  - ISS alternate access, optimum investment, reduction of LCC
  - US market share, employment, commercialization



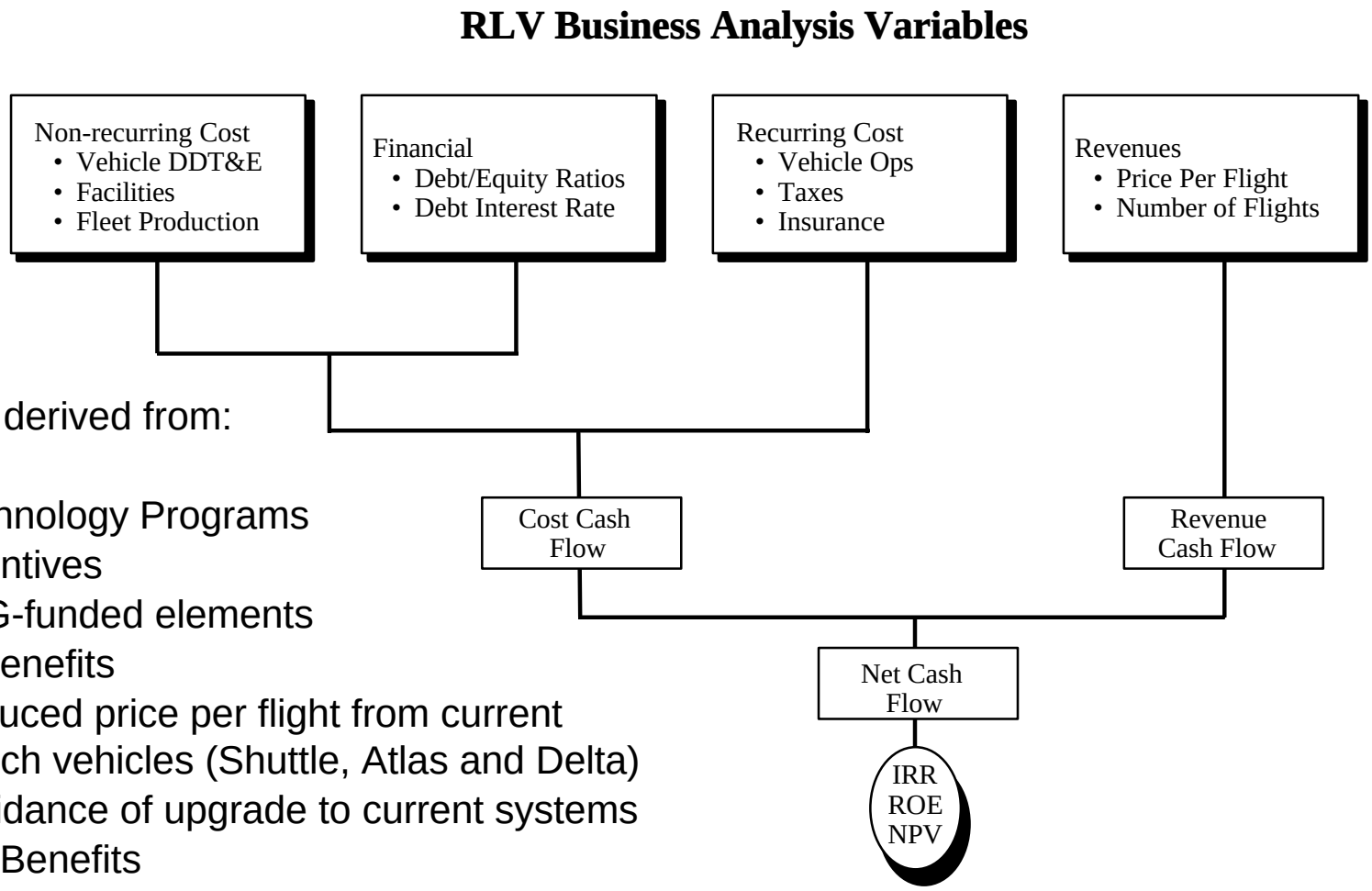
Economic Modeling

The New Launch Vehicle Economics

Costs versus Benefits



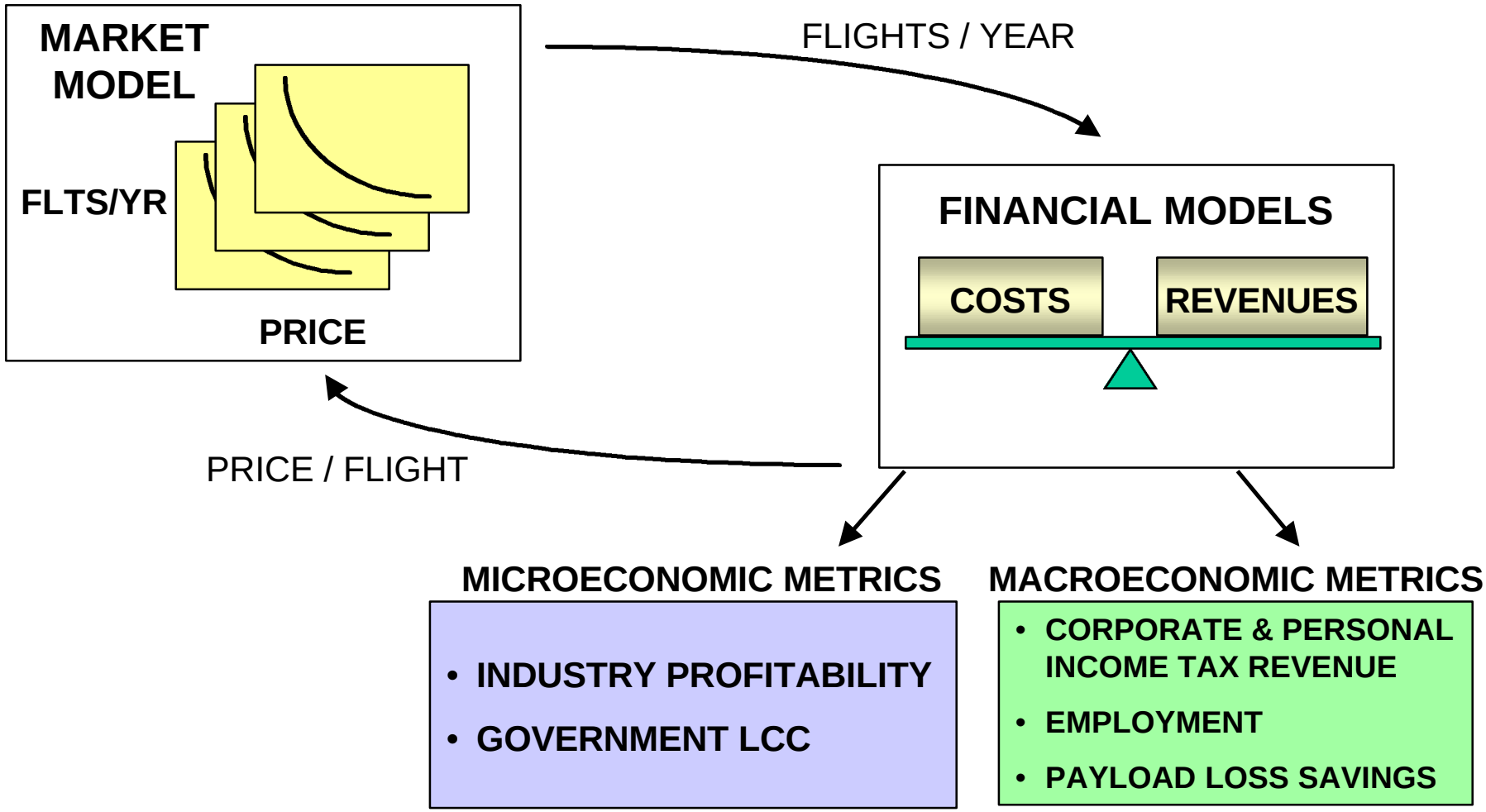
Economic Variables and Metrics



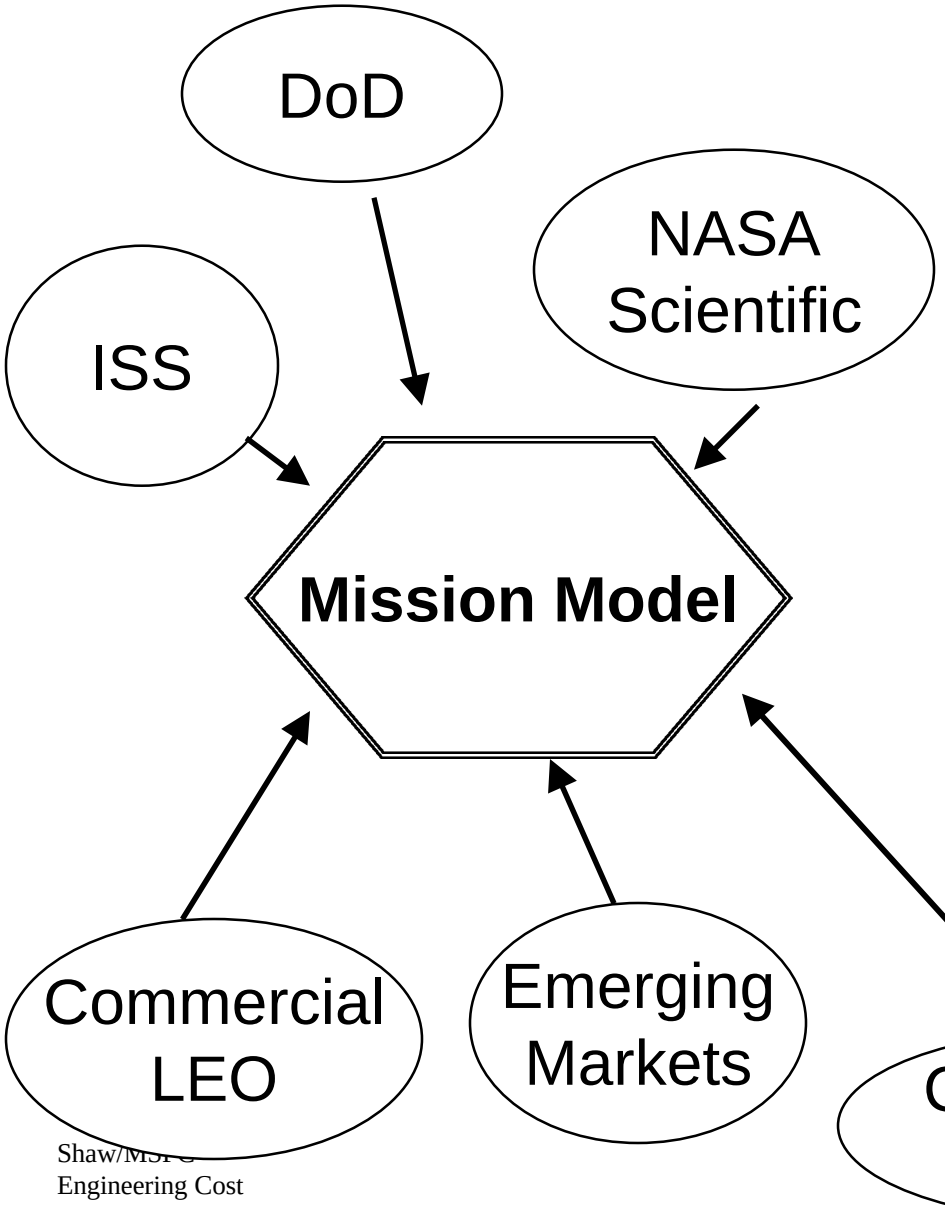
USG IRRs and NVPs derived from:

- Costs
  - Technology Programs
  - Incentives
  - USG-funded elements
- Direct Benefits
  - + Reduced price per flight from current launch vehicles (Shuttle, Atlas and Delta)
  - + Avoidance of upgrade to current systems
- Indirect Benefits
  - + Increased Tax Benefits (Payroll and Corporate)
  - + Job Creation

RLV Business Model



Mission Model



- Assess the Vehicle's Capability to Support ISS Servicing
- Determine the Potential to Leverage the Commercial Marketplace to Reduce NASA's Cost
- Evaluate the Vehicle's Ability to Expand the Space Economy
- Sources
  - NASA (ISS Servicing)
  - STAS Guidelines (NASA Science)
  - NMM (DoD, NASA Science)
  - FAA (Commercial LEO)
  - COMSTAC
  - CSTS

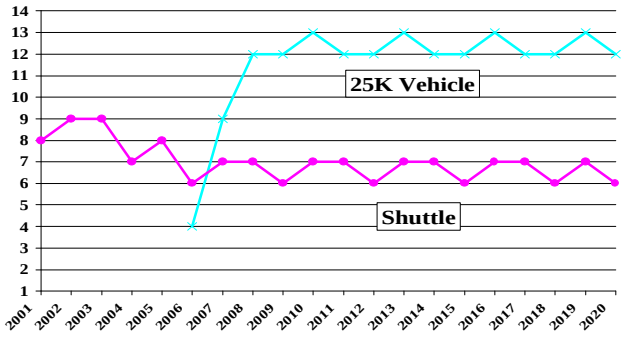
Market Model

Segment

ISS Servicing

- Marquee Vehicle Captures all Flights (if Capable)
- Linear Transition Rate from Shuttle

Demand Curve Assumption

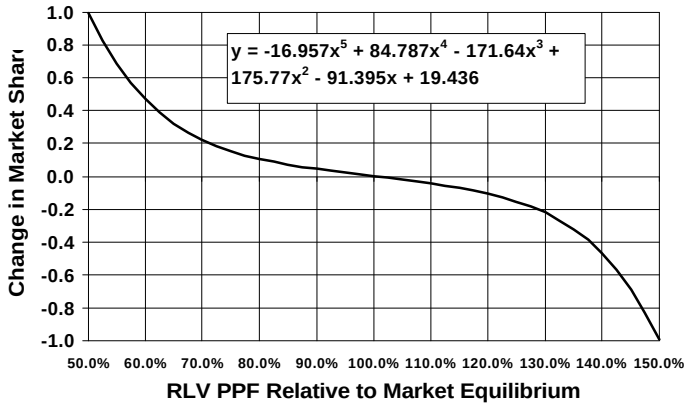


Summary Notes

- Two Vehicle Classes: Shuttle Equivalent and 25K lbs to ISS
- IOC and Transition Period are User Inputs
- CRV Rotation and Contingency Flight Included

Commercial

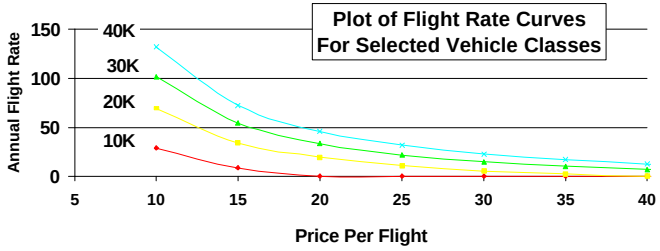
- Commercial GTO, Commercial LEO, DoD and NASA Scientific
- Competitors: Current and Future ELV's & RLV's
- Data from COMSTAC, FAA, DoD, NASA, ISIR, AIAA, EELV Companies



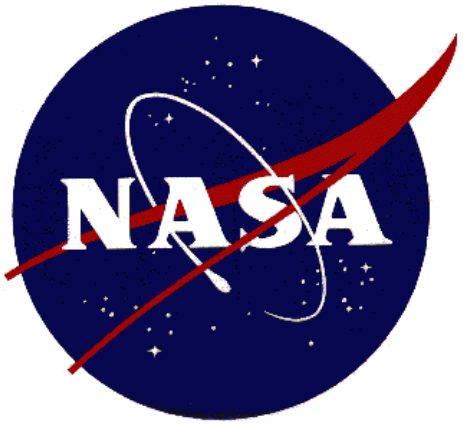
- Economic Theory of Oligopoly used to Determine Market Capture
  - At market equilibrium, competing vehicles share markets (1/N each)
  - Vehicle gains/loses market as price is set lower/higher
- Model Driven by Vehicle Capability and Price Per Flight

Emerging

- New (speculative) Business Opportunities
- Captures all Flights



- Summary Data from CSTS
- User Selects Demand Curve Sensitivity
- Driven by Price and Vehicle Capability



Economic Metrics

Architecture Evaluation: What Should Economics Measure?

To get the right answers, we must ask the right questions.

Customer	STAS In-House	Expanded ISTP Metrics Set
• **NASA**	Architecture Life-Cycle Cost (LCC) to NASA	" Probability of Price < $1000/lb " Probability of Reduced LCC " Safety Increase/Unit LCC " Near-Term Investment Req't
• **USG/ OMB**	Architecture LCC to NASA	" Return on USG Investment " Value of Competition
• **Industry**	Before-Tax Return on Equity	" Probability of Business Case Closure (All Metrics)
• **Public**	Emerging Market Price per Flight	" Probability of Significant Price Reductions

" **We have the methods, but we do not yet have sufficient data.**

ISTP Economic Metrics Approach

- Must reflect broad ranges of diverse stakeholders' Goals
  - NASA, other USG, Launch Industry, Current and Future Customers, US Public
- Four Metrics identified for Economic Assessment
  - $1000 per Pound (the only stated economic requirement), Average Price to LEO
    - Recommendation: to standardized low-earth orbit, average across all market segments
    - Measures long-term benefit to all potential users of space, including NASA
    - Emphasizes recurring costs, market factors, reduced USG share, emerging market
  - NASA Near-Term Investment
    - NASA appropriations/outlays 2000-2005 most heavily weighted, then 2006-2010
    - Measures budgetary and political challenge of required near-term investment
    - Emphasizes NASA technology and development incentive investments
  - Architecture Discounted LCC to NASA/USG
    - All Life-Cycle Costs discounted at low rate (7% market)
    - Measures Total Life-Cycle Cost to NASA for Space Transportation
    - Emphasizes price to NASA, NASA-unique element costs, life-cycle incentives
  - Business Case Closure (incl. Project IRR, BTROE, ATNPV)
    - Measures business planning, corporate strengths, concept design marketability
    - Emphasizes planning maturity; corporate experience, strategy, resources; market fit

Economic Metric Influences: $1000 Price per Pound (average to LEO, all customers)

- **Pricing strategy ****
  - NASA share (%) of revenue base
  - market analysis/capture strategy
  - emerging market commitment
- **Launch market conditions**
- **Operations cost***
- **Upper stage cost***
- **Fleet production cost***
  - technical parameters*
  - environment **
    - best commercial practices
- **Catastrophic reliability (hull insurance/self-insurance cost)***
  - graceful degradation
  - system operating margin
  - benign subsystem interactions
  - streamlined maintenance

Note: The $/lb metric has been defined various ways. “Operations” or “Recurring” Cost of $1000/lb would be easier to achieve than “Price,” but Ops Cost is not a complete measure of affordability. “Cost to NASA” would be the most challenging definition of all, since NASA requirements would be the most challenging (and costly) for a Gen2 system, and it would not account for benefits for other customers. Calculating the $/lb metric as Price, to a standard LEO over all customers, provides a unique measure of life-cycle affordability for all stakeholders.

* technical influences

** business plan influences

Economic Metric Influences: NASA/US Government Near-Term Investment

- **Technology/advanced development cost***
  - magnitude/phasing
  - applicability to other concepts
  - contractor cost sharing
- **NASA-unique element cost***
  - cost impact of safety req'ts
  - DDT&E, facilities and production costs
- **Shuttle/Gen2 RLV transition schedule* ****
- **Earth-to-Orbit System DDT&E/Facilities cost (& req'd USG cost share)**
  - concept design technical parameters*
  - environment**
    - best commercial practices
    - design maturity
- **Other USG Development Incentives****
  - Government-Guaranteed Loan
  - NASA Advance Purchase Agreements
  - R&E Tax Credit

* technical influences
** business plan influences

Economic Metric Influences: Architecture Discounted Life Cycle Cost to NASA/USG

- **ETO System price per flight****
  - launch market conditions
  - pricing strategy
  - Industry share of DDT&E and facilities costs
  - operations cost
  - fleet production cost
- **US Government Life-Cycle Incentives****
- **Shuttle/Gen2 RLV transition schedule* ****
- **NASA-unique element life-cycle costs***
- **Catastrophic reliability (payload loss cost)***
- **Architecture Expandability* ****
- **ETO System-dependent NASA LCC impacts***
  - mission reliability (payload loss costs)
  - cost impacts of safety requirements
  - cost impacts of extended design reference missions

* technical influences

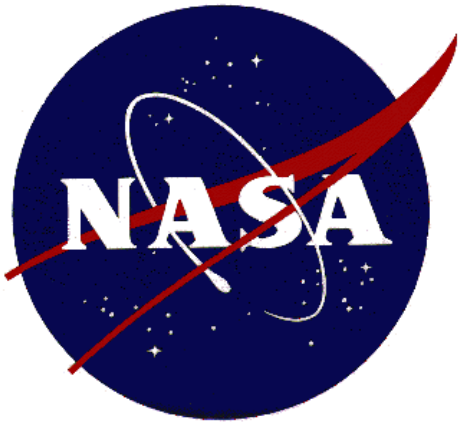
** business plan influences

Economic Metric Influences: Industry Business Case Closure

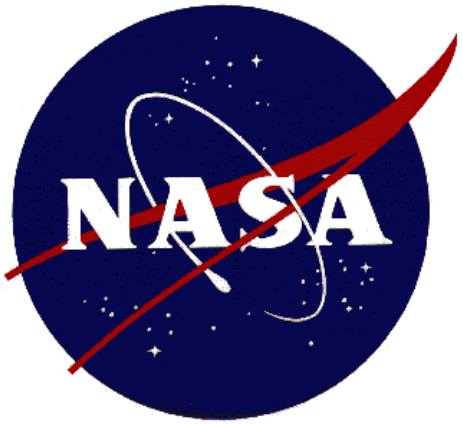
- **Corporate strategy and requirements****
- **Financing terms****
- **Launch market conditions**
- **Operations cost***
- **ETO System DDT&E and facilities cost ****
- **Customer attractiveness* ****
- **Shuttle/Gen2 RLV transition schedule* ****
- **Fleet production cost***

* technical influences

** business plan influences

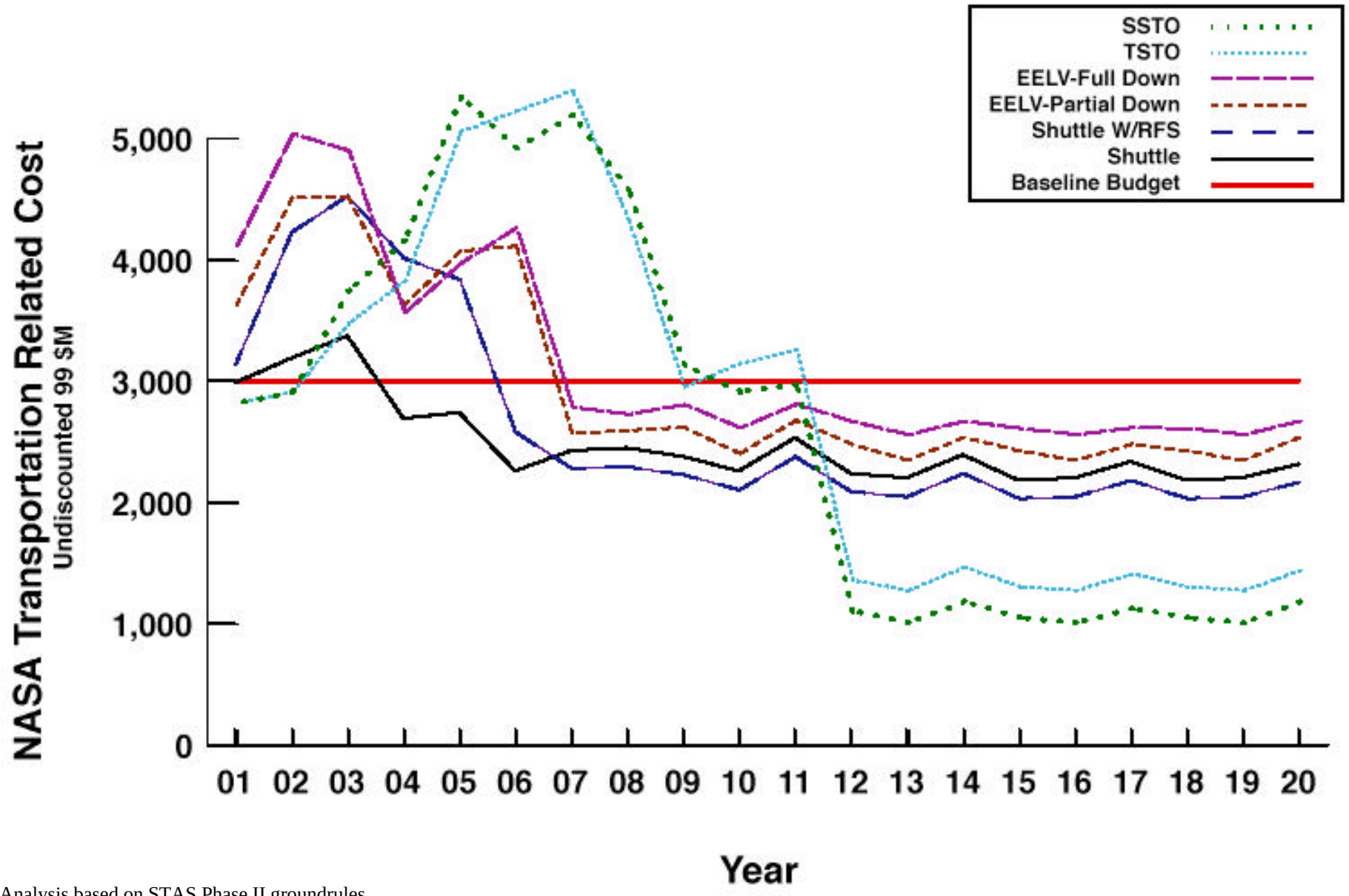


Other Related Topics



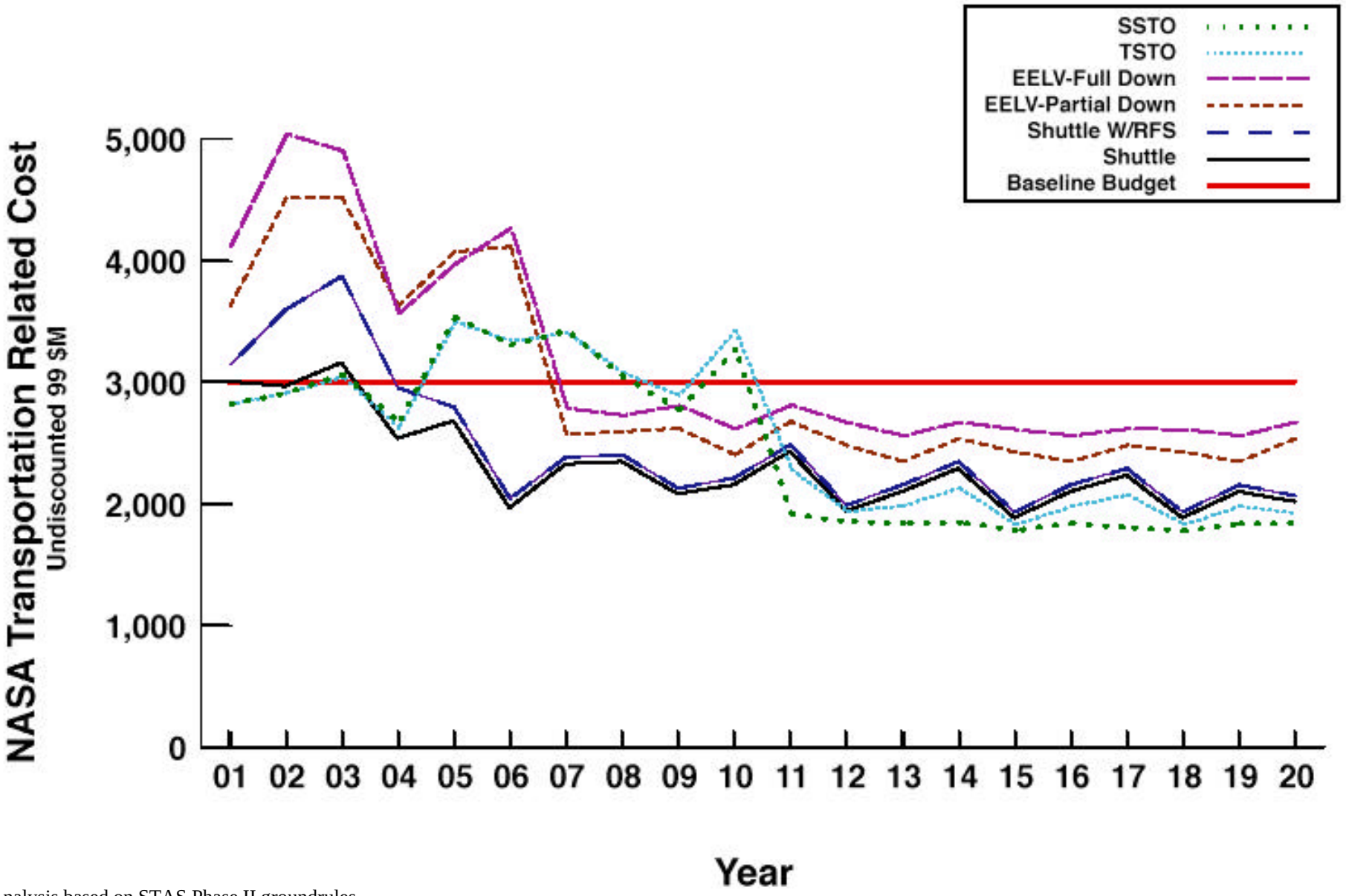
STAS NASA Internal Study Team Results

Cash Flow Analysis – USG Funded
Comparison of Architectures



Analysis based on STAS Phase II groundrules and STAS NASA In-House Team assumptions

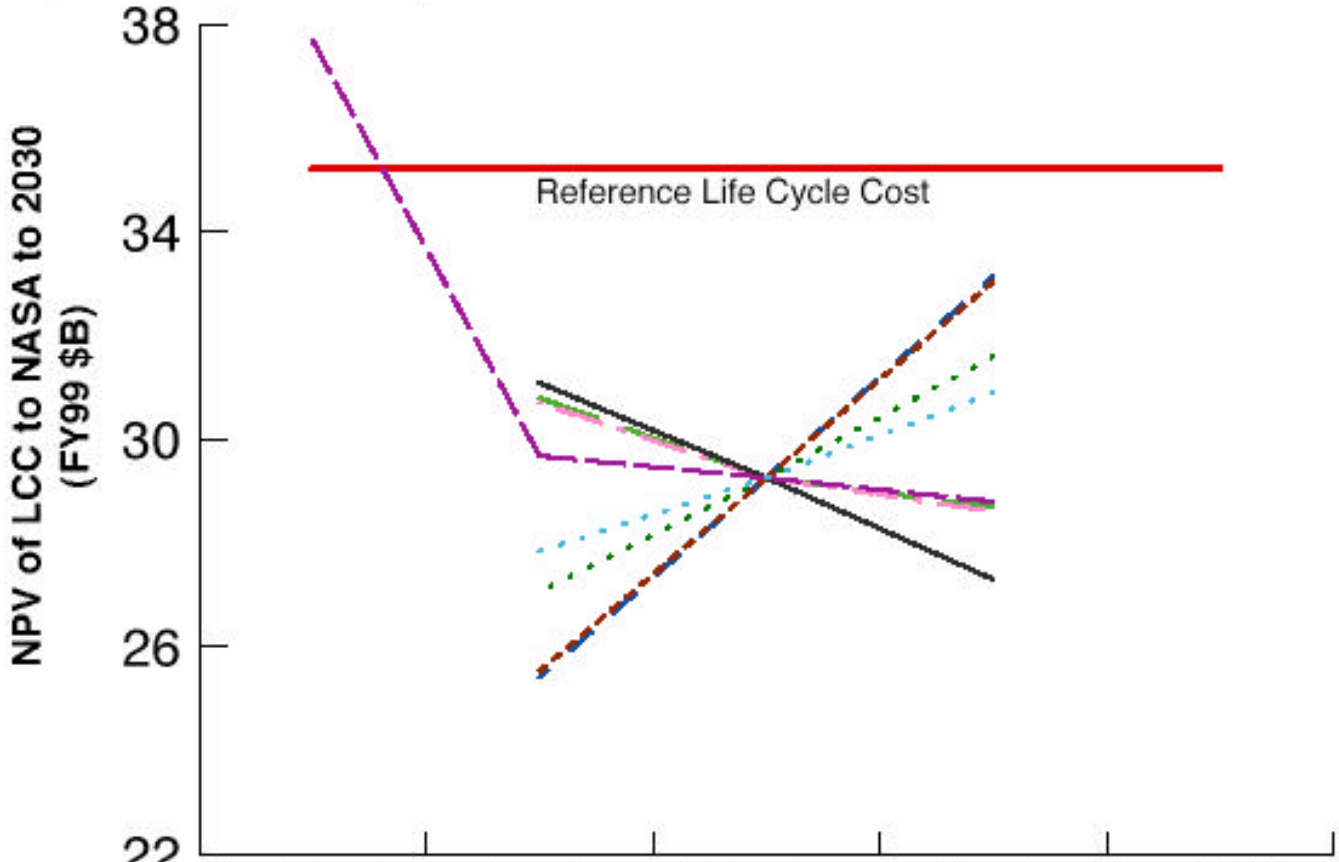
Cash Flow Analysis – Commercial Case
Comparison of Architectures



Analysis based on STAS Phase II groundrules and STAS NASA In-House Team assumptions

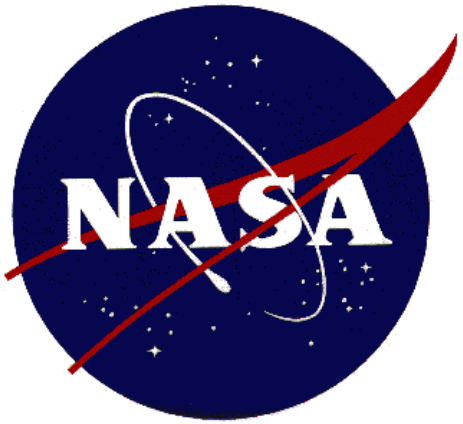
Engineering Cost

Sensitivity Analysis – Commercial Case Architecture 5



Analysis based on STAS Phase II groundrules and STAS NASA In-House Team assumptions

	Very Low	Low	Medium	High	Very High
Hurdle Rate		20%	25%	30%	
Incentives	None	Loan Only	Loan + $1B	Loan + $2B	
DDT&E $		50%	-	150%	
Unit Cost $		50%	-	150%	
Operations Cost $		50%	-	150%	
Comm'l Market Capture		50%	-	150%	
Comm'l Market Ave. Price		75%	-	125%	
Emerging Market Response		None	$1,000/lb	$2,000/lb	



Incentive Effects on Industry Metrics

Definition

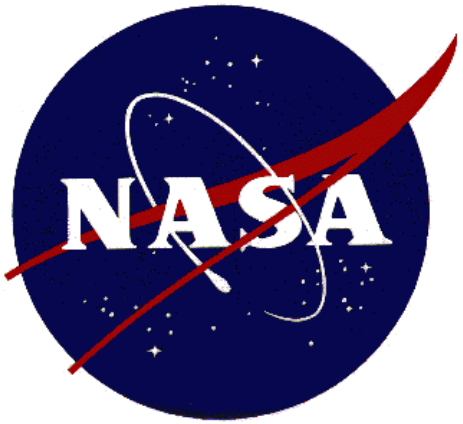
- **Incentives** are possible actions by the US Government (USG) to encourage commercial development of space transportation systems
  - Advance Purchase Agreements
  - Third-Party Liability Indemnification
  - In-Kind Contributions or Cost Share (Equity or Grant)
  - Government Guaranteed Loans
  - Tax Credits/“Holidays”
- USG Incentive Costs could be outlays or risk exposure

Effects of USG Incentives on Industry Metrics

- US Government (USG) Equity Investment
  - Increases all Industry metrics, USG shares in profit & risk
  - Dilutes Industry equity share, potential Industry loss of control
- Government Cost Share
  - Increases all metrics, decreases risk -> decreases hurdle rates
  - Reduced USG benefit, perhaps recover in flight discount coupons
- Government-Guaranteed Loans
  - Increases equity metrics (BTROE, ATNPV), decreases hurdle rates
  - Increased USG risk, no historical data for risk subsidy calculation
- Advance Purchase Agreements
  - Qualified effect on metrics; covers debt service, decreases hurdle rates
  - Requires up-front appropriations for effectiveness; approps may be required to equal total projected cost of system if USG market is greater than 60% of total
- Negotiable Development Deductions
  - Preserves tax benefits of development expenses for small start-ups
- R&E Tax Credit - Increases ATNPV, current effectiveness very low
- Tax "Holiday" - Small increase in ATNPV
- Targeted Tax Rebates - Increases ATNPV

Effects of USG Incentives on Industry Metrics

	Project IRR	BTROE	ATNPV (15%)
New Design Baseline Cases	Hurdle / Value	Hurdle / Value	Hurdle / Value
With Incentives			
- Current Technology:	25% / 15.8%	35% / 25.7%	$0 / $0.9B
- Advanced Development:	20% / 19.5%	30% / 34.8%	$0 / $1.1B
Relative effects per unit discounted USG cost:			
USG Cost Share/Equity	+1.4 to 1.6%	+2.0 to 4.3%	+$115-230M
USG -Guaranteed Loans	-5 to -10%	+3.9 to 6.7%	+560 to 670M
Advance Purchase Agreements	-5 to -10%	-5 to -15%	0
R&E Tax Credit	0	0	+$280 to 290M
Tax “Holiday”	0	0	+$250 to 280M



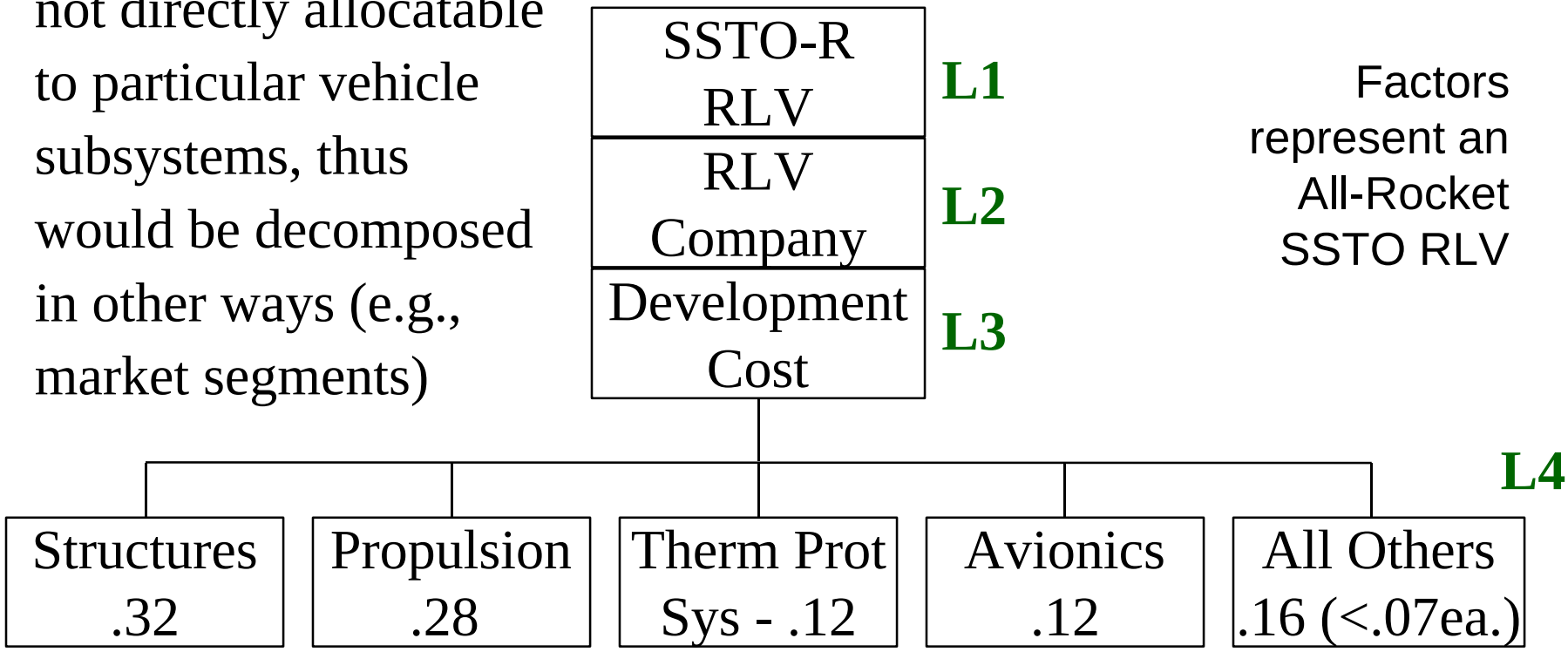
Technology Prioritization and the EBS

Economic Breakdown Structure

- Disaggregates discounted costs and revenues into components by timing, size and investor
  - time phases: technology, design, production, ops
  - subsystems: structures, engines, TPS, avionics
  - elements: flight & ground ops, market segments
  - investors: USG, commercial developer, customers, society
- Allows derivation of quantitative criteria weighting factors
  - based on reference concept cost, revenue, discount
  - factors for detailed subjective &/or quantitative evaluation
- Goal: valid deductions on economic impact from “short answers” about technologies

SSTO All-Rocket RLV EBS, Level Four

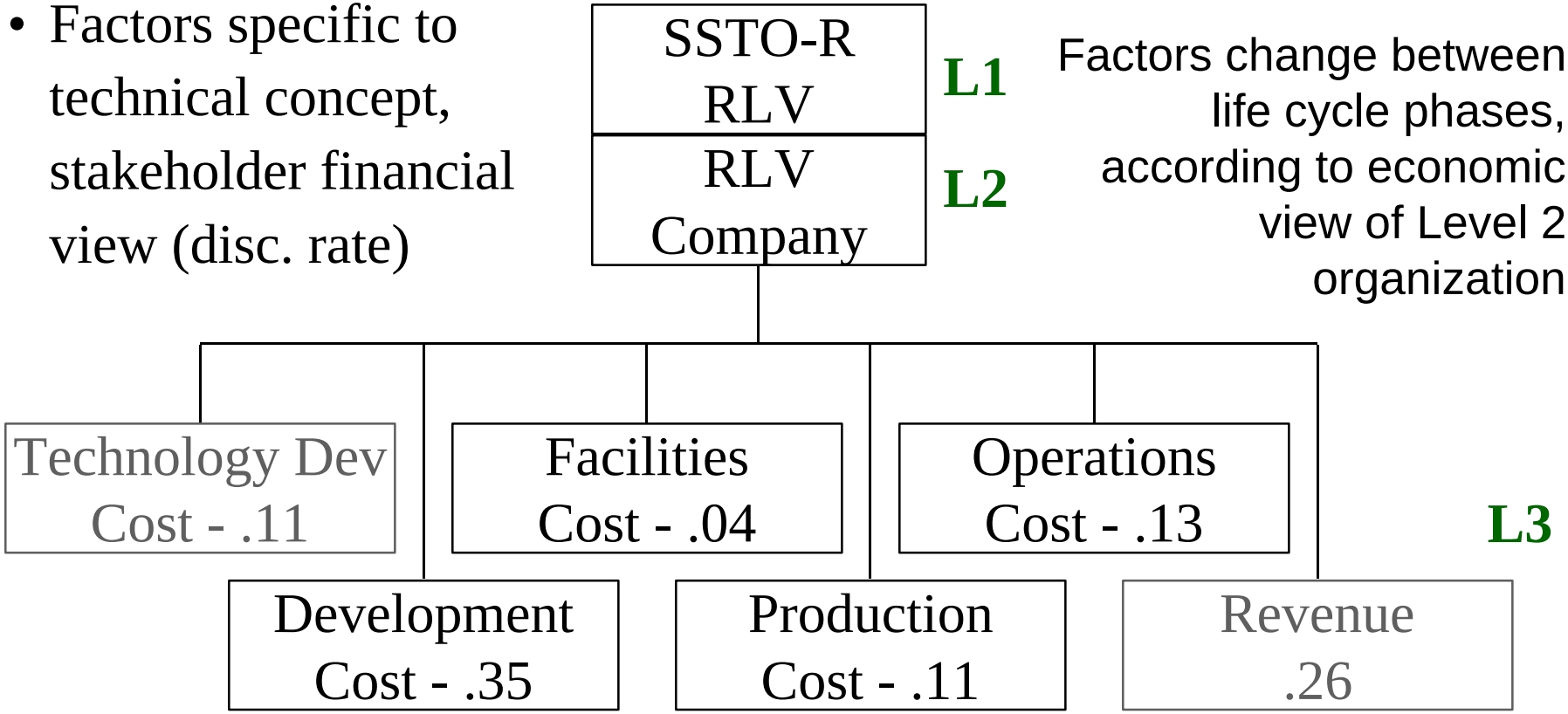
- This example decomposes **development cost** by **subsystem**
- Based on historical cost data and past studies
- Other life cycle economics elements (operations cost, revenue) not directly allocatable to particular vehicle subsystems, thus would be decomposed in other ways (e.g., market segments)



Factors represent an All-Rocket SSTO RLV

SSTO All-Rocket RLV EBS, Level Three

- This example decomposes the commercial effort in the launch vehicle project into **life cycle phases**, which can be weighted according to NPV, using discount rate for Level 2 org (RLV Co.)
- Factors specific to technical concept, stakeholder financial view (disc. rate)



Economics Breakdown Structure

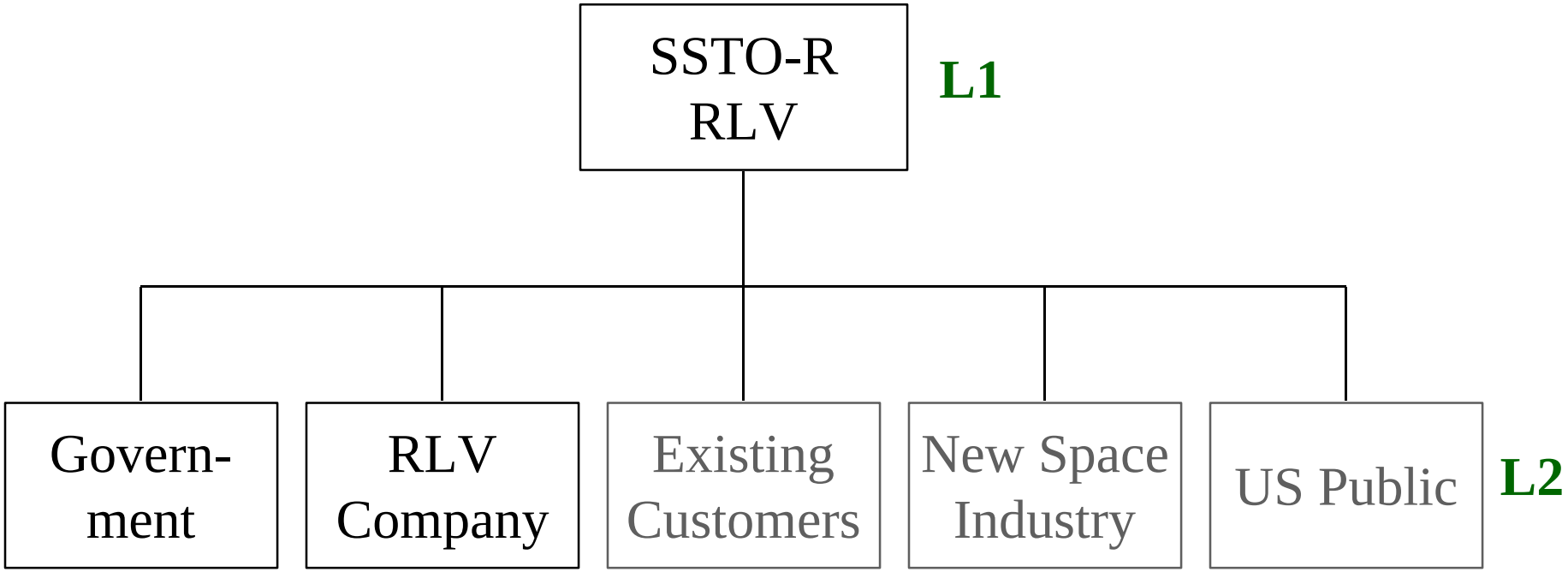
Commercial View

Subsystem	% of DDT&E	% of Production	Wt in USG Dev (14%)	**Wt in Ind Dev (35%)**	Wt in USG Prod (8%)	**Wt in Ind Prod (11%)**
Structures	32%	50%	4.5%	**11.2%**	3.8%	**5.7%**
TPS	12%	9%	1.6%	**4.0%**	0.7%	**1.0%**
Avionics	12%	5%	1.6%	**4.0%**	0.4%	**0.6%**
Power	3%	2%	0.4%	**0.9%**	0.2%	**0.2%**
Engines	28%	22%	3.9%	**9.7%**	1.6%	**2.4%**
Other Propul	7%	6%	1.0%	**2.6%**	0.5%	**0.7%**
RCS	4%	5%	0.6%	**1.6%**	0.3%	**0.5%**

Also includes **technology (11%), facilities (4%), operations (13%), revenue (26%)**

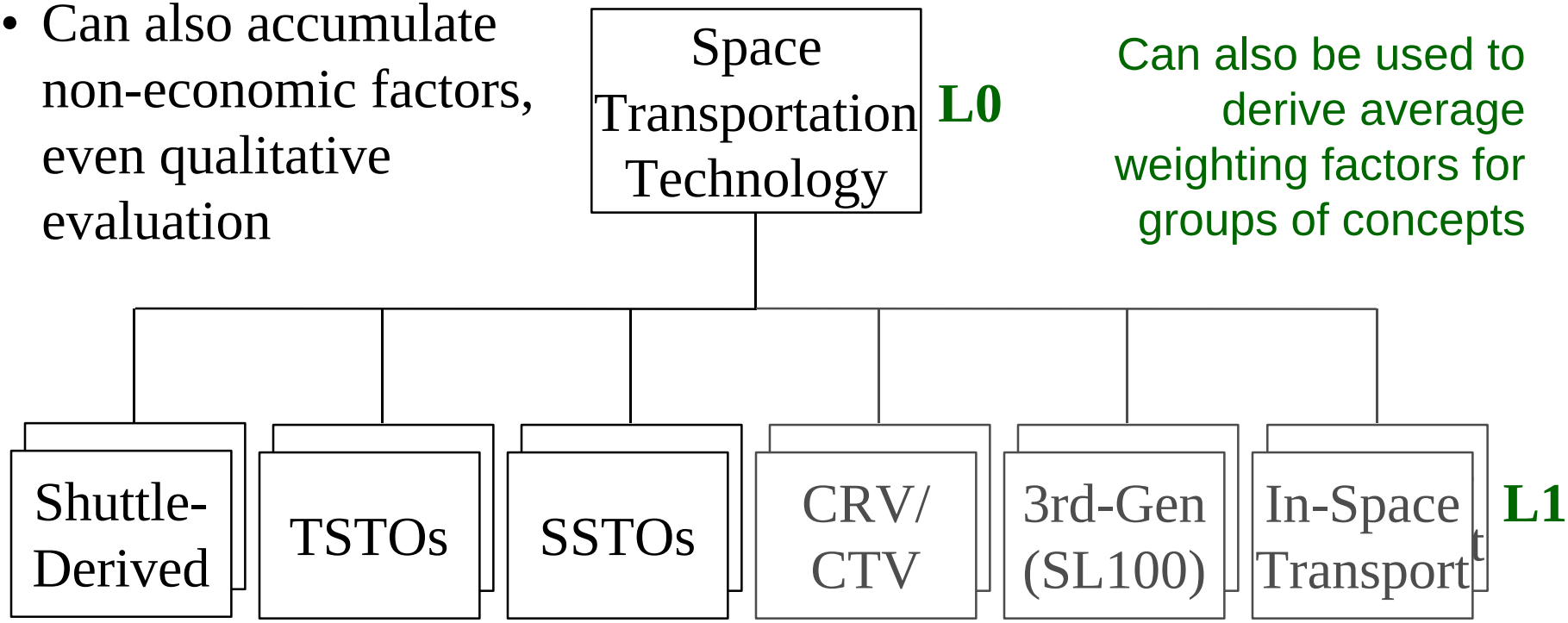
SSTO All-Rocket RLV EBS, Level Two

- Decomposes the economics of a launch vehicle architecture by **various investors, customers and other stakeholders**
- Determination of weighting factors between stakeholders problematic (requires management involvement)



Space Transportation EBS, Level Zero

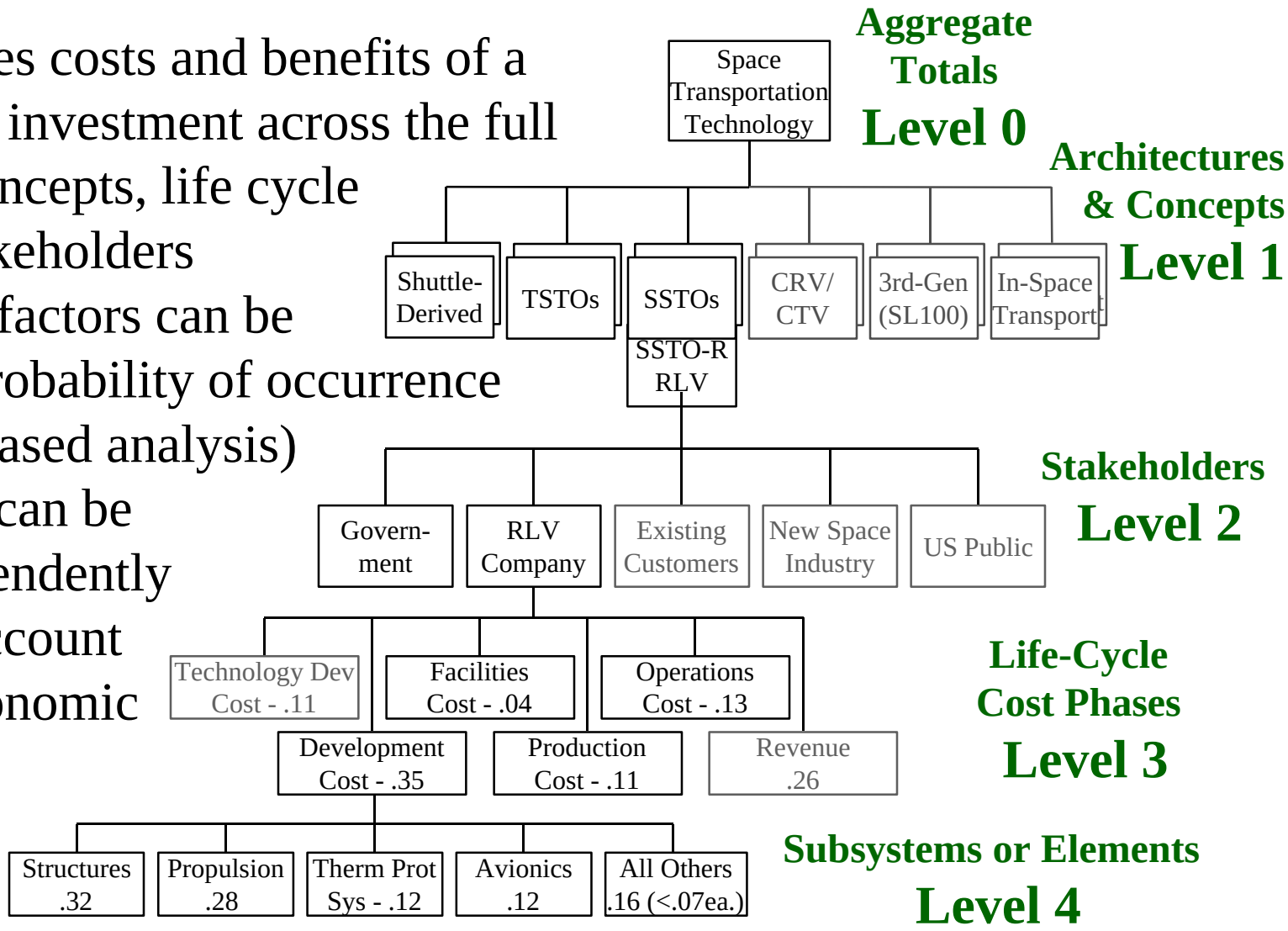
- Accumulates the costs and benefits of a technology investment across multiple representative concepts
- Weighting factors can be based on strategic benefit, potential for realization and/or time to benefit (management involvement)
- Can also accumulate non-economic factors, even qualitative evaluation

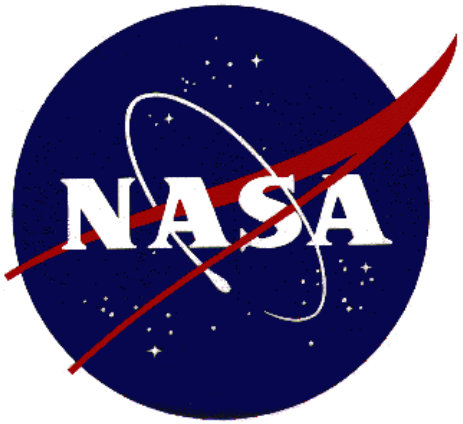


Can also be used to derive average weighting factors for groups of concepts

Space Transportation EBS, All Levels

- Accumulates costs and benefits of a technology investment across the full range of concepts, life cycle phases, stakeholders
- Weighting factors can be based on probability of occurrence (scenario-based analysis)
- Each level can be used independently
- Can also account for non-economic factors





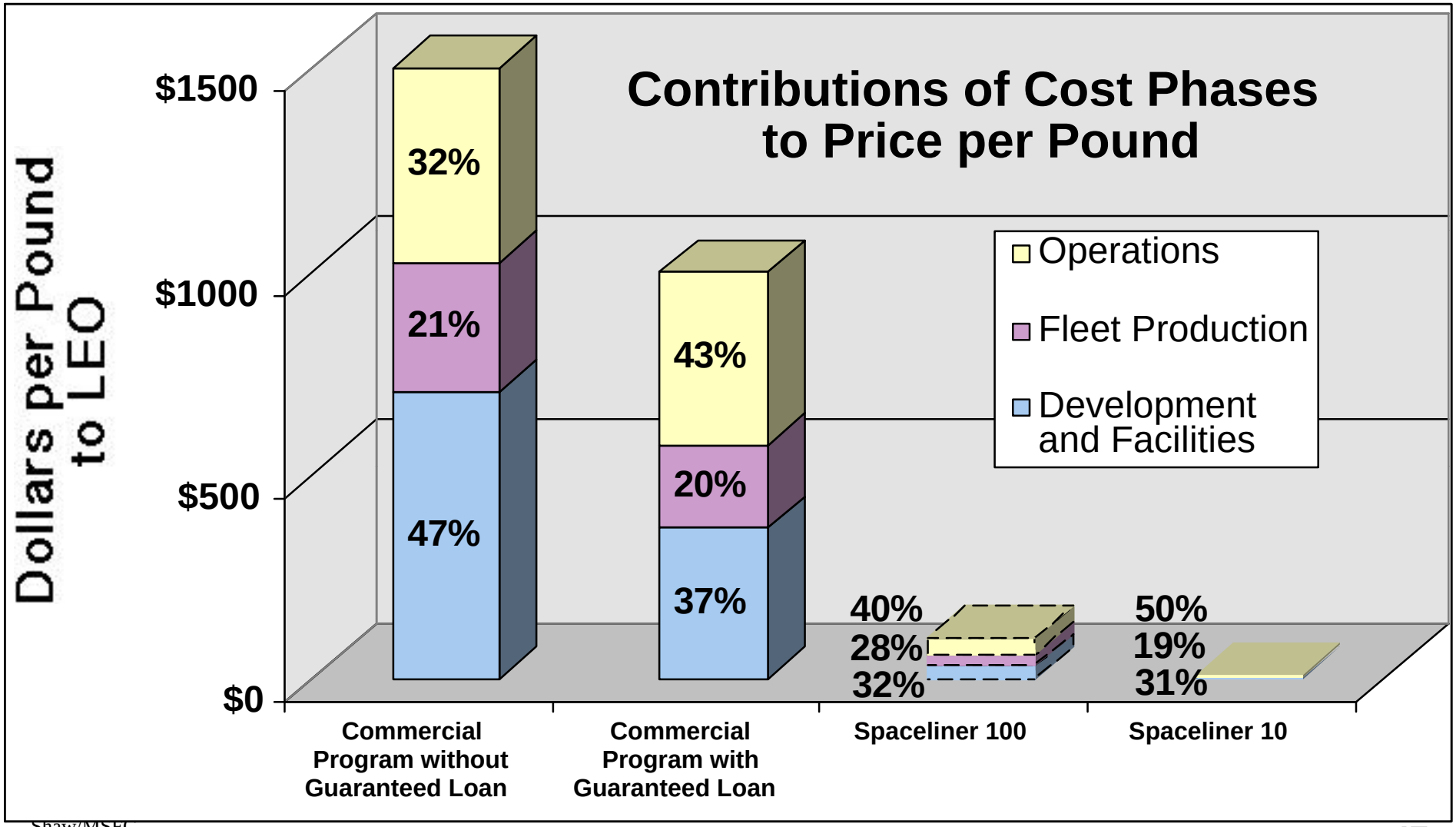
Five Generations to Public Space Travel

Four Generations of Airliners That Led to Routine Public Air Travel

Wright Flyer	**1903**	**1 'seat'**	**40 mph**	**fabric/wood**
Ford Trimotor	**1927**	**12 seats**	**110 mph**	**aluminum**
DC-3	1933	21 seats	180 mph	aerodynamic
DC-7	**1953**	**105 seats**	**360 mph**	**supercharged**
Boeing 707	**1954**	**147 seats**	**550 mph**	**turbojet**
Boeing 747	**1969**	**385 seats**	**550 mph**	**turbofan, wide-body**
(Concorde	1969	144 seats	1350 mph	supersonic mach 2.05)
(Boeing 767	1981	211 seats	550 mph	twin-jet, glass cockpit)
Boeing 777	1994	360 seats	550 mph	fly-by-wire

First Generation (Partially) Reusable Launch Vehicle
Space Shuttle 1981

Economic Progression from Second Generation (with & without Guaranteed Loan) to Fourth Generation



Routine Public Space Travel: Reaching the Fifth Generation

- Enabling routine public space travel will require a logical progression through several generations of launchers
- Order-of-Magnitude improvements will be needed in one or more primary areas in each generation
  - Safety
  - Cost
  - Market
- Improvements in commercial systems will be motivated by business economics
- Improvements can also be carried along by wars and other events

In the end, though, we will never get to
the Fifth Generation and airline-like launch operations
if we never build a Second-Generation Reusable Launch Vehicle.